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EXPERT CONSULTATION ON
CORAL BLEACHING
Manila, 11-13 October 1999

REPORT OF THE EXPERT CONSULTATION ON CORAL BLEACHING

Background

In section II of its decision IV/5, on coral reefs, the Conference of the Parties to the Convention on Biological Diversity requested its Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to analyse the coral-bleaching phenomenon, the potentially severe loss of biological diversity and consequent socio-economic impacts. On this basis, in order to assist the work of SBSTTA on the topic at its fifth meeting, to be held in Montreal from 31 January to 4 February 2000, the Executive Secretary of the Convention convened an Expert Consultation on Coral Bleaching. The Consultation took place at the headquarters of the International Center for Living Aquatic Resources Management (ICLARM) in Manila, Philippines, from 11 to 13 October 1999.

Part I of the present document contains the conclusions and recommendations of the Expert Consultation on priority areas for action on the issue of coral bleaching, and part II contains the report of the meeting.

I. CONCLUSIONS AND RECOMMENDATIONS ON PRIORITY AREAS FOR ACTION

A. Information-gathering

Issue: Our ability to adequately project, and thus mitigate, the impacts of global warming on coral reef ecosystems and the human communities which depend upon coral reef services is limited by the paucity of information on:

(a) The taxonomic, genetic, physiological, spatial, and temporal factors governing the response of corals, zooxanthellae, the coral-zooxanthellae system, and other coral-reef-associated species to increases in sea surface temperature;

(b) The role of coral reefs as critical habitat for marine species and natural resources for human communities;

(c) The current status of coral-reef health and threats to coral reefs; and

(d) The potential capacity of recovery 1/ of corals and resilience of the ecosystem after mass mortality.

Response:

(a) Implement and coordinate targeted research programmes, including predictive modelling, that investigate: (1) the tolerance limits and adaptation capacity of coral-reef species to acute and chronic increases in sea surface temperature; (2) the relationship among large-scale coral bleaching events, global warming, and the more localized threats that already place reefs at risk; and (3) the frequency and extent of coral bleaching and mortality events, as well as their impacts on ecological, social and economic systems.

(b) Implement and coordinate baseline assessments, long-term monitoring, and rapid response teams to measure the biological and meteorological variables relevant to coral bleaching, mortality and recovery, as well as the socio-economic parameters associated with coral reef services. To this end, support and expand the Global Coral Reef Monitoring Network (GCRMN) and regional networks, and data repository and dissemination systems including ReefBase - the Global Coral Reef Database. Also, the current combined Swedish International Development Agency (SIDA)/Swedish Agency for Research and Cooperation (SAREC) and World Bank programme on coral-reef degradation in the Indian Ocean (CORDIO), as a response to the 1998 coral-bleaching event, could be used as an example.

(c) Develop a rapid response capability to document coral bleaching and mortality in developing countries and remote areas. This would involve the establishment of training programmes, survey protocols, availability of

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1/ Recovery is the return of a coral colony to a state of health, including a symbiotic relationship with zooxanthellae, after the health and/or symbiotic relationship has been disrupted by a stress or perturbation. Recovery may involve a change in the genetic composition of species of the zooxanthellae. Resilience is the return of a coral reef ecosystem to a state in which living, reef-building corals play a prominent functional role, after this role has been disrupted by a stress or perturbation. A shift toward high dominance by frondose algae accompanied by a reduction in the functional role of coral would indicate a situation of low resilience.

expert advice, and the establishment of a contingency fund or rapid release of special project funding.

(d) Encourage and support countries in the development and dissemination of status-of-the-reefs reports and case studies on the occurrence and impacts of coral bleaching.

Issue: The remoteness of many coral reefs and the paucity of funding and personnel to support on-site assessments of coral reefs require that remote-sensing technologies are developed and applied in the evaluation of coral-bleaching events.

Response: Extend the use of early-warning systems for coral bleaching by:

(a) Enhancing current National Oceanic and Atmospheric Administration (NOAA) advanced very high resolution radiometer (AVHRR) "hotspot" mapping by increasing resolution in targeted areas and carry out ground-truth validation exercises;

(b) Encouraging space agencies and private entities to maintain deployment of relevant sensors and to initiate design and deployment of specialized technology for shallow oceans monitoring; and

(c) Making the products of remote sensing readily accessible to coral reef scientists and managers worldwide with a view to those scientists and managers that are based in developing countries.

B. Capacity-building

Issue: There is a substantial lack of trained personnel to investigate the causes and consequences of coral-bleaching events.

Response: Support the training of and career opportunities for marine taxonomists, ecologists, and members of other relevant disciplines, particularly at the national and regional level.

Issue: Coral bleaching is a complex phenomenon. Understanding the causes and consequences of coral bleaching events requires the knowledge, skills, and technologies of a wide variety of disciplines. Any action aimed at addressing the issue should bear in mind the ecosystem approach, incorporating both the ecological and societal aspects of the problem.

Response: Encourage and support multidisciplinary approaches to coral reef research, monitoring, socio-economics and management.

Issue: Public awareness and education are required to build support for effective research, monitoring, and management programmes, as well as policy measures.

Response: Build stakeholder partnerships, community-participation programmes, and public-education campaigns and information products that address the causes and consequences of coral bleaching.

C. Policy development/implementation

Issue: Nearly 60 per cent of the world's coral reefs are threatened by localized, human activities which have the potential to exacerbate the impacts of coral-bleaching events. Evaluations of the 1998 coral-bleaching events suggest that marine protected areas alone may not provide adequate protection for at least some corals and other reef-associated species as sea-surface temperatures rise.

Response: Use existing policy frameworks to implement the multiple conservation measures outlined in the ICRI Renewed Call to Action, and develop and implement comprehensive local to national-scale integrated marine and coastal area management plans that supplement marine protected areas.

Issue: Most coral reefs are located in developing countries and the majority of the people living near coral reefs are often extremely poor. Thus, even minor declines in the productivity of coral-reef ecosystems as a result of coral-bleaching events could have dramatic socio-economic consequences for local people who depend on coral-reef services.

Response: Identify and institute additional and alternative measures for securing the livelihoods of people who directly depend on coral-reef services.

Issue: Coral bleaching is relevant not only to the Convention on Biological Diversity but also to the United Nations Framework Convention on Climate Change and the Convention on Wetlands. The ultimate objective of the United Nations Framework Convention on Climate Change is to reduce emissions in a manner that allows "ecosystems to adapt naturally" to climate change. The United Nations Framework Convention on Climate Change calls upon Parties to take action in relation to funding, insurance, and technology transfer to address the adverse effects of climate change. The Convention on Wetlands provides guidance on the conservation and wise use of wetlands, including coral reefs.

Response: Initiate efforts to develop joint actions among the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, and the Convention on Wetlands to:

(a) Develop approaches for assessing the vulnerability of coral reef species to global warming;

(b) Build capacity for predicting and monitoring the impacts of coral bleaching;

(c) Identify approaches for developing response measures to coral bleaching; and

(d) Provide guidance to financial institutions, including the Global Environment Facility, to support such activities.

Issue: Coral bleaching has the potential to impact local fisheries, as well as certain high-value commercial pelagic fisheries and coastal ecosystems.

Response: Encourage the Food and Agriculture Organization of the United Nations (FAO) and regional fisheries organizations to develop and implement measures to assess and mitigate the impacts of sea-surface temperature rise on fisheries.

Issue: Coral-bleaching events are a warning of even more severe impacts to marine systems. If anomalous seawater temperatures continue to rise, become more frequent, or are prolonged, the physiological thresholds of other organisms will be surpassed. Not only will local fisheries be impacted, but certain high-value commercial pelagic fisheries and coastal ecosystems will be affected as well.

Response: Emphasize that coral bleaching can be monitored as an early warning of the impacts of global warming on marine ecosystems and that the collapse of coral-reef ecosystems could impact ecological processes of the larger marine system of which coral reefs are a part.

Issue: The observations of the 1998 coral-bleaching events suggest that coral reef conservation can no longer be achieved without consideration of the global climate system and that it requires efforts to mitigate accelerated global climate change.

Response: Emphasize the interdependencies and uncertainties in the relationships among marine, terrestrial, and climatic systems.

D. Financing

Issue: Because the issue of climate change is global and long-term in scale, governments around the world need to work together to make funds available to implement initiatives to address the causes and consequences of coral bleaching.

Response: Mobilize international programmes and mechanisms for financial and technical development assistance, such as the World Bank, UNDP, the Global Environment Facility, regional development banks, as well as national and private sources to support implementation of these priority actions.

II. REPORT OF THE MEETING

1. OPENING OF THE MEETING

1. The Expert Consultation on Coral Bleaching was held under the auspices of the Secretariat of the Convention on Biological Diversity at the premises of the International Center for Living Aquatic Resources Management (ICLARM), Manila, from 11 to 13 October 1999. The Consultation was attended by 20 experts invited from a regionally balanced selection of countries and international organizations. The full list of participants is contained in annex I below.

2. Dr. Peter Gardiner, Deputy Director-General (Programs) of ICLARM, called the Expert Consultation to order at 9.30 a.m. on 11 October 1999. He thanked the coordinators and sponsors of the meeting expressed his appreciation to all the experts for accepting the invitation on short notice and, for many, over a quite long distance. Dr. Gardiner said that ICLARM had a longstanding tradition of research on coral reefs, including issues relevant to bleaching, and that much was expected of the current meeting. He declared the Expert Consultation officially open and wished all participants success.

3. Dr. John McManus, ICLARM Senior Scientist and Project Leader of ReefBase - the Global Coral Reef Database, welcomed the participants and expressed ICLARM's appreciation for the invitation by the Executive Secretary of the Convention on Biological Diversity to host the meeting.

4. Mr. Salvatore Aricò, Secretariat of the Convention on Biological Diversity, welcomed the participants on behalf of Mr. Hamdallah Zedan, Executive Secretary of the Convention. He thanked the experts for making themselves available and the Governments of France, Sweden and the United States of America, as well as IUCN-The World Conservation Union (United States office), for their generous financial contribution for the organization of the meeting. He said that holding the meeting at ICLARM was a natural consequence of the concrete cooperation that had been established between the Convention and the ICLARM secretariats in the area of conservation and sustainable use of marine and coastal biological diversity. Mr. Aricò provided the context for the expert consultation and an overview of the products to be prepared, which will be elaborated upon in the context of the administrative arrangements.

2. ORGANIZATIONAL MATTERS

2.1. Administrative arrangements

1. The Secretariat briefed the participants on the administrative arrangements for the Consultation, which included the election of a Chairperson and of a Rapporteur.

2.2. Election of the Chairperson and Rapporteur

1. It was agreed that Dr. McManus, as the expert from the host organization, should serve as Chairperson of the Consultation, and Dr. Jamie Reaser, expert from the United States of America, should serve as Rapporteur.

2.3. Adoption of the agenda

1. The provisional agenda as circulated in advance by the Secretariat (UNEP/CBD/JM/Expert/2/1) was adopted with the addition of items on analysis and prediction, response measures and linkages with other processes. It was also agreed that the question of coral bleaching in relation to the ecosystem approach should be taken into account in the presentations and discussion on all the substantive agenda items. The agenda as adopted is contained in annex II to the present report.

2. The Chairperson proposed a timetable to facilitate the work of the meeting and identified the experts to introduce specific aspects of coral bleaching.

2.4. Overview of the documentation

1. The Secretariat introduced the documentation for the meeting, a list of which is contained in annex III below.

3. OBJECTIVES OF THE EXPERT CONSULTATION

1. The Chairperson, with the assistance of the Secretariat, explained that, through its decision IV/5, section II, on coral reefs, the Conference of the Parties to the Convention had requested its Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to analyse the coral-bleaching phenomenon, the potentially severe loss of biological diversity and consequent socio-economic impacts. The Expert Consultation had been convened in order to assist the work of SBSTTA on the topic at its fifth meeting, to be held in Montreal from 31 January to 4 February 2000, and as a response to SBSTTA recommendation IV/1 A, paragraph 6, in which the Subsidiary Body urged the Executive Secretary to make rapid progress on the issue. The Secretariat explained that the main outputs of the meeting were expected to be an analysis of the coral-bleaching phenomenon to assist the Executive Secretary in the preparation of his note on the subject for the fifth meeting of SBSTTA (the "pre-session document"); and expert recommendations on scientific, technical and technological aspects of coral bleaching, based on the most recent findings on the phenomenon. The report of the meeting would be made available as an information document at the fifth meeting of SBSTTA.

4. GENERAL INTRODUCTION TO THE ISSUE OF CORAL BLEACHING

1. The Chairperson invited Dr. Clive Wilkinson, Coordinator, Global Coral Reef Monitoring Network (GCRMN) to provide an overview of recent coral-bleaching events, on the basis of information gathered through GCRMN.

2. Dr. Wilkinson said that, since the early 1980s, the major factors causing persistent damage to coral reefs were anthropogenic: increased sedimentation, pollution and over-exploitation, especially through damaging practices like using dynamite and cyanide. The situation had changed radically in the late 1990s with rising global temperatures compounding the threats of direct anthropogenic stresses. The catalyst had been the severe El Niño Southern Oscillation (ENSO) event of 1997/98. He demonstrated the example of the latitudinal progress of elevated sea-surface temperatures (SSTs) as "hotspots" in the Indian Ocean observed in analyses from the United States National Oceanic and Atmospheric Administration (NOAA) in the first

half of 1998, which was followed by severe coral bleaching and mortality on coral reefs in its path. The El Niño event collapsed in June 1998, and immediately seasonal trade winds recommenced and water temperatures cooled. An equally strong La Niña event started immediately and this resulted in elevated SSTs in South-East and East Asia with similar levels of coral bleaching and mortality. During these ENSO events, severe coral bleaching was also observed in the Red Sea and the Gulf region, on inshore areas of the Great Barrier Reef, and in parts of the Caribbean. However, vast areas of the Pacific and the Red Sea were relatively unaffected, with the exception of Palau and the southern Red Sea.

3. A report written in late 1998 using data and information provided through the Internet showed that there was "catastrophic bleaching" (bleaching and a mortality rate of up to 95 per cent of coral cover and species) in large parts of the Indian Ocean (Oman, Maldives, Sri Lanka) and other areas such as Singapore and Bahrain. There had been "severe bleaching" (50-70 per cent coral mortality) in Kenya, Seychelles, the United Republic of Tanzania, Thailand, Viet Nam, Japan and Palau. In the Caribbean and the Atlantic region, there had been reports of severe bleaching in Belize, Puerto Rico, Bahamas, the Cayman Islands, Florida, Bermuda and Brazil, but many of the bleached corals had subsequently recovered. Moderate and patchy bleaching had been observed on the Great Barrier Reef, Madagascar, Philippines and Indonesia. Current models of global climate change projected that ENSO events were increasing both in frequency and intensity, with the likelihood of far greater impacts to coral reefs in the future. Currently available evidence suggested that major events such as the 1998 bleaching were directly related to accelerating global climate change.

4. GCRMN had been established under the International Coral Reef Initiative with two goals: (i) to obtain data and information on the status and trends in coral reefs; and (ii) to raise awareness in users, Governments, donors and agencies on the problems facing reefs. Dr. Wilkinson suggested that monitoring should be increased to involve all potential stakeholders: scientists, Governments and the community. He requested the assistance of participants and others to assist in the expansion of GCRMN to all regions of the world and in the preparation of two products: a revised report on the status of coral reefs one year after the 1997/98 ENSO event (deadline: December 1999) and the <u>Status of Coral Reefs of the World: 2000</u> report (due for release in October 2000).

5. Dr. Wilkinson identified the following key points:

(a) The major factors causing increased coral-reef degradation up to 1998 were direct anthropogenic impacts;

(b) Increased sea-surface temperatures and other effects linked to increasing variations and changes in climate were now augmenting these threats to the world's coral reefs;

(c) Bleaching in 1998 had resulted in the death of more than 80 per cent of corals and associated species on many coral reefs around the world, resulting in major threats to biological diversity;

(d) There was a need for enhanced capacity for surveying and monitoring in all countries with coral reefs to ensure that clear, unambiguous signals of potential global climate change damage could be documented.

1. The Chairperson invited participants to provide the meeting with any information on bleaching events in different geographical regions they may wish to add to Dr. Wilkinson's presentation. Dr. Tim McClanahan (Wildlife Conservation Society, Kenya), Dr. Robin South (Marine Studies Programme of the University of the South Pacific), Dr. Ed Gomez (Marine Science Institute of the University of the Philippines) and Dr. Ernesto Weil (Department of Marine Sciences of the University of Puerto Rico) briefly reported on the occurrence of bleaching in the Indian Ocean, the Pacific island States, the Philippines and the Wider Caribbean, respectively.

2. Dr. Yossi Loya (Department of Zoology, Tel Aviv University) and Dr. Roberto Iglesias-Prieto (National Autonomous University of Mexico) then reviewed the physiological and evolutionary aspects of coral bleaching.

3. Dr. Loya reported on the status of corals in Okinawa, Japan, focusing on the status before and after the 1998 bleaching event, which followed a significant average increase of 2.5°C in sea-surface temperatures over the average for the previous 10 years. A direct result of the increase in sea-surface temperatures was mass mortality of 85 per cent of the stony and soft coral populations. Coral mortality was species-specific. The bleaching heavily impacted the most prolific corals on Okinawa reefs: the branching Acropora corals. Paradoxically, the juvenile intertidal Acropora colonies survived. With regard to their survival characteristics, he categorized the corals as "winners" and "losers". "Winners" were the massive and encrusting coral species; "losers" were generally branching corals with high surface-to-volume ratios and soft corals. He suggested that mass transfer and passive diffusion principles might explain why some corals survived while others did not. He also showed several slides from permanent quadrats on his study area to illustrate conditions before and after bleaching and progressive changes on individual colonies and species. He also discussed the adaptive capability of some coral species found in very shallow and exposed reefs. Based on metapopulation theory, he suggested that a decline in coral populations beyond a threshold would eliminate certain species from the region.

4. Dr. Loya identified the following key points emerging from his studies:

(a) There had been a drastic decrease in stony-coral diversity (from 81 species to 40) and local extinction of some previously abundant coral species, with no evidence of recruitment;

(b) Current information on changes to coral communities following coral bleaching was very limited and there were no projections concerning the long-term effects on coral community structures;

(c) There was a need to monitor and investigate the extent recovery rates, resilience and adaptability of corals with respect to increasing sea-surface temperatures and bleaching.

1. Dr. Iglesias said that the symbiosis between dinoflagellates (zooxanthellae) and invertebrates was the key to understanding the coral-bleaching phenomenon. His most recent studies, focusing on algae-and-host interactions in relation to thermal stress were based on questions such as whether thermal stress was sensed by the animal and transferred to the algae or vice versa. Analyses of the responses of individual associations indicated that elevated seawater temperature negatively affected the photosynthetic apparatus of symbiotic algae. Although there was still debate over the actual

site of damage, there was a consensus that inactivation of algal photosynthesis was the underlying mechanism of coral bleaching. Once algal photosynthesis was impaired, exposure to other stressors such as visible and ultraviolet light or reduced water motion would exacerbate the effects of thermal stress. Further studies on thermal stress provided data on the limits of tolerance of different coral species and showed that zooxanthellae, which were not genetically uniform, have different ranges of thermal tolerance. There was a need to look into individual responses of different hosts and zooxanthellae to clarify their role during coral bleaching, and to evaluate their potential to acclimatize to elevated sea-surface temperatures.

2. Dr. Iglesias identified the following key points emerging from his research:

(a) The temperature-dependent impairment of algal photosynthesis initiated coral bleaching;

(b) The species-specific thermal tolerance ranges of individual coral species depends largely on the presence of specific algal symbionts.

1. In ensuing discussion, some experts referred to the role of factors other than increase in sea-surface temperatures having significant physical and biological impacts on coral reefs, such as hurricanes and bacteria, which might be linked with the bleaching phenomenon. However, those aspects were not sufficiently known, and it was difficult to establish a clear correlation between them and coral bleaching.

2. Several participants confirmed that the problems described for Okinawa were typical of vast areas of coral reef around the world over the previous two years. They confirmed that coral bleaching had occurred on an unprecedented scale.

5. IMPACTS OF CORAL BLEACHING ON MARINE AND COASTAL BIOLOGICAL DIVERSITY

1. The Chairperson invited Dr. McClanahan and Dr. Gomez to illustrate the issue of potential severe loss of biological diversity due to coral bleaching and to provide relevant examples.

2. Dr. McClanahan reported on coral cover in several reefs in the Indian Ocean region and his comparisons of these occurrences with historical information. He concluded that coral populations in the area were severely devastated following the massive bleaching of 1998. Since then, he had not found any evidence of coral recruitment within marine parks but there had been outside. In Kenya, a 20-40 per cent loss of species had been observed along transects by both himself and Dr. Nyawira Muthiga of the Kenyan Wildlife Service. Some species were at such low densities they did not appear in the transects. Patchiness of coral and brown algae was affected by herbivores. Sites still looked patchy one year later. Some sites had switched to a predominance of brown algae and turf algae. Herbivores such as sea urchins and fish dominated, and in parks further loss of coral cover had been observed as a result of consumption of the substrate by scraping and excavating herbivorous fish. Consumers played an important role in whether the reefs entered in phase-shifts from coral to brown algae. Brown algae reduction experiments had been conducted, as phase-shifts to brown algae suppressed herbivorous fishes and other carnivores. Once algae were removed, the number of herbivores doubled. The net production of the new systems (with brown

algae) was low. No big differences in catches as a result of bleaching had been observed in Kenya, but the reefs had already been degraded in the first place. As fifty per cent of the total fish catch came from seagrass beds and 20 per cent from pelagic sources, loss of coral as a result of bleaching did not have much impact. Fish populations had to be looked at in more detail, in order to detect changes in species. A comparison of coral recruitment inside and outside park areas indicated that parks had the lowest-density recruitment of corals and might therefore require restoration measures.

3. Dr. McClanahan identified the following as key points emerging from his studies:

(a) The highest coral mortality rates had occurred in parks as a result of the presence of bleaching-sensitive species; in parks, mortality levels stood at 80 per cent;

(b) Reefs with high coral mortality and low herbivore abundance shifted towards brown algal reefs one year later;

(c) The experimental reduction of brown algae suggested a lower abundance and diversity of fishes on brown algal reefs;

(d) Recruitment of corals in parks was low and might result from the abundance of consumers feeding on the remaining corals.

1. Dr. Gomez said that the Philippines had experienced an extreme bleaching event in 1998. It was temperature-related and caused the loss not only of large amounts of corals, but also of thousands of giant clams. In some places, fish also died, which was unusual. In addition to dead bleached clams, giant clams had also died without bleaching. Sea urchins and other invertebrates died on the reef flat. There might be extreme situations, when the water got so warm for so long in conditions of hypoxia that fish, giant clams and other species died in addition to corals. The observed temperature had been 34°C and had stayed at that level for several days. The water had been calm, stagnant and clear. Ocean nurseries of giant clams with seagrass had fared better than those without. The shading provided by seagrass, which had been reported to alleviate coral bleaching elsewhere, might have had the same effect on giant clams. That aspect was worth investigating in the future, particularly in terms of the effect of vegetation on dissolved oxygen in addition to shading. In less extreme events, bleaching might be partial and selective. Recent studies on zooxanthellae indicated the presence of genetically diverse symbionts on the same coral colony. To understand bleaching better, it was necessary to focus more attention on the symbiosis between corals and zooxanthellae.

2. The key points identified by Dr. Gomez were:

(a) Extreme temperature regimes over reefs could cause mass mortalities of organisms independently of bleaching;

(b) Strategic research on zooxanthellae-host relationships was needed to explain bleaching phenomena.

1. There followed a general discussion on the impacts of coral bleaching on marine and coastal biological diversity.

6. SOCIO-ECONOMIC IMPACTS OF CORAL BLEACHING

1. The Chairperson invited Dr. Herman Cesar (Institute of Environmental Studies, Free University of Amsterdam) to outline the actual and likely socio-economic impacts of coral bleaching.

2. Dr. Cesar gave an overview of the economics of coral-reef deterioration with specific reference to bleaching. He described the impacts of coral bleaching and subsequent mortality on the economic and ecological services of coral-reef ecosystems. Specifically, reef fisheries, coastal protection, and coastal tourism could be seriously affected. In addition, health impacts from bleaching-related ciguatera poisoning could be severe. Coastal villages in developing countries were typically poor and dependent on coastal resources and coral reefs for their livelihood. Degradation of coral-reef ecosystems was a major threat to sustainable fisheries production, and coral bleaching could exacerbate this situation. Hence, health impacts from coral bleaching could also include malnutrition due to declining fish production, loss of income and employment. It was difficult to put a precise value on the socio-economic damages from bleaching because of the uncertain causal relationships and thresholds in impacts. Current socio-economic research under the CORDIO 2/ programme in the Maldives, Sri Lanka, the United Republic of Tanzania and Kenya, among other countries, showed large uncertainties in possible impacts. It also appeared that many socio-economic impacts would be especially felt in the medium and long term.

3. The key points identified by Dr. Cesar were:

(a) The socio-economic impacts of coral bleaching were likely to be severe, especially if episodes of coral bleaching became more frequent in the future;

(b) Coastal villages in developing countries were already impoverished because of natural-resource degradation, and coral bleaching was likely to exacerbate that situation, possibly leading to further malnutrition and poverty.

1. There followed an exchange of views on issues related to socio-economic impacts of coral bleaching.

7. ANALYSIS AND PREDICTION

1. The Chairperson invited Dr. Jamie Oliver (Great Barrier Reef Marine Park Authority, Australia), Dr. McManus and Dr. Wilkinson to introduce the issue of analysis and prediction of coral bleaching.

2. Dr. Oliver summarized current perspectives on the analysis and prediction of coral bleaching, using the example of the Great Barrier Reef. He highlighted the need to look at bleaching thresholds to understand what was causing bleaching and to predict coral bleaching in the future. Satellite technology would also be crucial to that end. Work with Dr. Al Strong of NOAA

2/ The programme on coral-reef degradation in the Indian Ocean (CORDIO) is funded by the World Bank through its World Bank-The Netherlands partnership and by the Swedish International Development Agency (SIDA)/Swedish Agency for Research Cooperation (SAREC).

showed that there was a high correspondence when bleaching threshold records were overlapped with global satellite sea-surface temperatures. He also spoke of the "Eye on the Reef Monitoring Program" and the use of aerial survey results as good ways to measure and monitor the incidence and severity of coral bleaching over broad scales. A similar overlay using the aerial surveys and global satellite SST data show a good correspondence as well. ENSO events, however, appeared to offer a loose explanation for coral-bleaching events. He also highlighted points of collaboration between the Australian Institute of Marine Science/Great Barrier Reef/NOAA, critical issues to be addressed and information needs. Finally, he reviewed the relationship between the frequency/intensity of bleaching and recovery time.

3. The key points identified by Dr. Oliver were:

(a) A proper understanding of the coral-bleaching phenomenon required a good record of the extent and severity of bleaching over time. That in turn required assessment and monitoring programmes that provided reliable data and included both negative and positive reports of the occurrence of bleaching;

(b) Aerial surveys could provide a cost-effective means for assessing bleaching on larger scales;

(c) Satellite data on sea-surface temperatures could be used to demonstrate the relationship between bleaching and temperature anomalies, and that technique should be developed further;

(d) The ability of corals and their zooxanthellae to adapt to higher temperatures was crucial to an understanding of the likely long-term effects of coral bleaching;

(e) Global climate models were also crucial in determining the effects of global warming on coral reefs. Those models needed to be verified for use at regional scales.

1. Dr. McManus presented evidence that widely used benthic sampling techniques were of limited use in assessing the health and potential resilience of coral reefs based on one-time analyses. However, those approaches provided a useful basis for analysing changes to coral reefs in inter-annual monitoring programmes. He therefore emphasized the need to strengthen monitoring programmes globally and to support the analysis of major reef problems and the development of effective management actions.

2. Dr. Wilkinson elaborated on the issue of analysis and prediction through the experience of GCRMN, which was not exclusively a scientific monitoring programme, but involved the development of a "network" of all potential stakeholders working on coral-reef assessment and monitoring. The current focus was on expanding governmental and non-governmental monitoring, targeting 80 countries with coral reefs. A critical point was that monitoring should not be an end in itself, but should be part of ongoing programmes aimed at conserving and managing coastal resources. The experiences of 1998 with the first global status report should be repeated every two years, but based on all countries producing national status reports, even though many Governments might not be fully prepared to write full reports. Dr Wilkinson stressed that the purpose of such a strategy was to require Governments to increase their involvement in monitoring and reporting. He sought assistance for the production of biennial national reports, which would be condensed into the global report. It was hoped that comparison of biennial reef reports within

regions would encourage countries to sustain monitoring activities and achieve similar reporting mechanisms. For the current year, efforts would focus on key case-studies of coral bleaching around the world to substantiate the preliminary reports from 1998. He also asked for assistance in producing those reports. Finally, he mentioned the need to establish a coordination project like CORDIO for South-east Asia, the Pacific and the Caribbean to facilitate setting up similar large-scale experiments and to be prepared for potential future bleaching events, for example, by using similar techniques for assessment of recovery and recruitment.

3. There followed a discussion on the analysis and prediction of coral bleaching.

8. RESPONSE MEASURES

1. The Chairperson invited Mr. Brian Crawford (Associate Coastal Resources Manager, Coastal Resources Center of the University of Rhode Island) to introduce the issue of response measures to the occurrence of coral bleaching.

2. Mr. Crawford covered four areas in his presentation: (i) the coastal managers perspective on coral bleaching; (ii) integrated marine and coastal area management (IMCAM) in the context of coral bleaching; (iii) response options; and (iv) recommended general policies and actions. He said that managers were interested in information on coral bleaching that answered management-relevant information needs concerning trends in coral bleaching and associated mass mortality, probable ecological and socio-economic impacts, responses that could be taken, and the extent to which future events could be forecast. Coastal managers' perspectives might vary. While a marine park manager might be concerned about biological-diversity conservation, the coastal manager outside protected areas might be more concerned about economic and development issues first and biological-diversity conservation second, particularly in developing countries.

3. IMCAM provided a framework for addressing local, subnational, and national coastal-resources-management issues, including coral bleaching. However, the responses that could be taken by local and national IMCAM initiatives were limited, and could not by themselves address the root causes of coral bleaching and associated coral mortality - global warming and elevated sea-surface temperatures. IMCAM efforts might become more difficult as those global events could totally overwhelm efforts to protect and preserve coral reefs from localized impacts. However, IMCAM was an important framework for local response that could address local issues relating to the degradation of coral-reef ecosystems. The maintenance of healthy coral-reef ecosystems through IMCAM initiatives could help minimize the damage caused by mass coral-bleaching events, as well as increase the speed of recovery.

4. IMCAM managers needed to be able to distinguish between coral-reef degradation as a result of globally caused coral bleaching and degradation from localized sources, and inform coastal communities and local policy makers of those facts. Possible responses to mass coral bleaching could be categorized as prevention, mitigation, disaster relief and rehabilitation. While there were specific responses that could be taken by area of impact (fisheries, tourism, coastal erosion, health), there were also some general responses that cut across all impact areas. Such responses included keeping reefs healthy from local impacts, supporting efforts to reduce carbon

emissions, and physical coral-reef restoration after bleaching events occurred.

5. Responses needed to be considered in terms of a one-time natural-disaster event that might require immediate relief and rehabilitation efforts, in addition to a series of events of increasing severity and frequency, requiring a range of responses. General policies and actions that could be considered included: (i) the promotion of public education and awareness-raising of senior officials, as well as the general public; (ii) the incorporation of coral-bleaching responses into local and national IMCAM programmes, as well as capacity-building and training programmes; and (iii) funding and supporting research and monitoring efforts on coral bleaching as part of overall research and monitoring components of coral-reef and IMCAM management programmes.

6. Mr. Crawford identified the following key points:

(a) General responses to coral-reef-ecosystem impacts associated with coral bleaching included education and awareness-raising among decision makers and the general public;

(b) IMCAM could provide a broad framework for local and national response to coral-bleaching impacts;

(c) Response strategies needed to consider coral bleaching not only as a natural phenomenon but also as a series of events of increasing frequency and severity;

(d) The effectiveness of local and national response strategies needed to be assessed, as there was little known on that subject.

1. Following the presentation on linkages with other processes (see paras. 1-3 below), there was a discussion on response measures and linkages with other processes.

9. LINKAGES WITH OTHER PROCESSES

1. Mr. Brett Orlando (IUCN, Washington Office) gave an overview of the linkages between coral bleaching and the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Wetlands of International Importance especially as Waterfowl Habitat. The ultimate objective of the climate change convention was to reduce anthropogenic emissions of greenhouse gases in a manner that allowed "ecosystems to adapt naturally" to climate change. The Convention also required its parties to take action in relation to funding, insurance, and the transfer of technology to address the adverse effects of climate change, including those on coral reefs. The Convention on Wetlands required its parties to conserve and wisely use wetland resources, which according to its article 1, paragraph 1, included coral-reef ecosystems. At its most recent meeting, the Conference of the Parties to the Convention had decided to initiate efforts to strengthen cooperation with the climate change convention, in light of the potential adverse effects of climate change on wetlands, and to undertake an assessment of those impacts. It had been concluded that opportunities for mutually reinforcing implementation of these agreements existed, but that immediate efforts by Governments, non-governmental organizations, and international institutions must be made to seize them.

2. One initial action would be to share the report of the current Expert Consultation with the Convention on Climate Change, the Convention on Wetlands, and the Intergovernmental Panel on Climate Change (IPCC). He stressed the importance of initiating a process between the Convention on Biological Diversity, the Convention on Climate Change, and the Convention on Wetlands to identify joint actions to address: (i) the prediction, monitoring, and assessment of vulnerability; (ii) the role of conservation and management in mitigating the impact of climate change; and (iii) the role of financial mechanisms, such as the Global Environment Facility, in supporting such activities.

3. Mr. Orlando identified the following key points:

(a) Addressing coral bleaching would require concerted action under the Convention on Climate Change and the Convention on Wetlands as well as the Convention on Biological Diversity;

(b) Such joint action should address the vulnerability of coral reefs to climate change; the role on conservation in mitigating potential impacts; and the need for financial mechanisms such as the Global Environment Facility to support such activities including through the transfer of know-how and environmentally sound technology.

1. There followed a discussion on response measures to coral bleaching and linkages with other processes.

10. CONCLUSIONS AND RECOMMENDATIONS

1. A summary of main points and issues of the presentations and discussion is contained in annex IV below. The conclusions and recommendations on priority areas for action that emerged from the discussions on the different agenda items are set out at the beginning of this document (pp. 2-5 above).

11. ADOPTION OF THE REPORT OF THE EXPERT CONSULTATION, INCLUDING THE APPROVAL OF THE DRAFT PRE-SESSION DOCUMENT FOR THE FIFTH MEETING OF THE SUBSIDIARY BODY ON SCIENTIFIC, TECHNICAL AND TECHNOLOGICAL ADVICE

1. The participants in the expert consultation considered the draft pre-session document for the fifth meeting of SBSTTA, which had been elaborated on the basis of document UNEP/CBD/JM/Expert/2/2. The participants approved the draft pre-session document.

2. The Rapporteur introduced the draft report of the meeting. After a brief discussion, the Expert Consultation adopted the draft report, as amended, by acclamation.

12. CLOSURE OF THE MEETING

1. After concluding remarks by the Secretariat and the representative of the host organization, thanking the donors and the organizers of the meeting and the participants for their efforts and most valuable contribution, the Expert Consultation was declared closed by the Chairperson at 2 p.m. on Wednesday, 13 October 1999.

Annex I

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Annex II

AGENDA

1. Opening of the meeting.

2. Organizational matters:

    2.1. Administrative arrangements;

    2.2. Election of the Chairperson and Rapporteur;

    2.3. Adoption of the agenda;

    2.4. Overview of the documentation.

3. Objectives of the Expert Consultation.

4. General introduction to the issue of coral bleaching.

5. Impacts of coral bleaching on marine and coastal biological diversity.

6. Socio-economic impacts of coral bleaching.

7. Analysis and prediction.

8. Response measures.

9. Linkages with other processes.

10. Conclusions and recommendations.

11. Adoption of the report of the Expert Consultation, including the approval of the draft pre-session document for the fifth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice.

12. Closure of the meeting.

Annex III

LIST OF DOCUMENTS

A. Documents prepared for the meeting

UNEP/CBD/JM/Expert/2/1	Provisional agenda
UNEP/CBD/JM/Expert/2/1/Add.1	Annotations to the provisional agenda
UNEP/CBD/JM/Expert/2/1/Add.2	List of documents
UNEP/CBD/JM/Expert/2/2	Analysis of the coral bleaching phenomenon, potential severe loss of biological diversity and consequent socio-economics impacts
UNEP/CBD/JM/Expert/2/Inf.1	Information for participants
UNEP/CBD/JM/Expert/2/Inf.2	Tentative list of participants
UNEP/CBD/JM/Expert/2/Inf.3	Decision IV/5 of the Conference of the Parties to the Convention on Biological Diversity: conservation and sustainable use of marine and coastal biological diversity, including a programme of work – section II: "coral reefs"
UNEP/CBD/JM/Expert/2/Inf.4	Compilation of submissions made by the experts

B. Other relevant documentation available at the meeting

1. Berkelmans, R. and B. L. Willis (1999). Seasonal and Local Spatial Patterns in the Upper Thermal Limit of Corals on the In-Shore Central Great Barrier Reef. Coral Reefs, Vol. 18: 219-228.

2. Berkelmans, R. and J. Oliver (1999). Large Scale Bleaching of Corals on the Great Barrier Reef. Coral Reefs, Vol. 18: 55-60.

3. Brown, B.E. Coral Bleaching: Causes and Consequences. Coral Reefs, Vol. 16: 129-138.

4. Gomez, E.D. and S.S. Mingoa-Licuanan (1998). Mortality of Giant Clams Associated with Unusually High Temperatures and Coral Bleaching. In: Watson, Maggie (Ed.) Reef Encounter No. 24, December 1998, and Newsletter of the International Society for Reef Studies.

5. Glynn, P. W. (1996). Coral Reef Bleaching: Facts, Hypotheses and Implications. Global Change Biology, Vol. 2: 495-509.

6. Linden, O. and N. Sporrong (eds.) (1999). Coral Reef Degradation in the Indian Ocean: Status Reports and Project Presentation.

7. Hoegh-Gulberg, O. (1999). Climate Change, Coral Bleaching and the Future of the World's Coral Reefs. Greenpeace publication series.

8. Loya, Y., K. Sakai, Y. Nakano, K. Yamazato and R. van Woesik. Coral Bleaching: Changing of the Guard (Ms.)

9. Pollnac, R. B. (1998). Rapid Assessment of Management Parameters for Coral Reefs. Coastal Resource Center, University of Rhode Island.

10. Reaser J.K., R. Pomerance and P.O. Thomas (1999). Coral Bleaching, Coral Mortality, and Global Climate Change. Journal of Conservation Biology (in press).

11. Olsen, S. B., J. Tobey and L.Z. Hale. A Learning-Based Approach to Coastal Management. Ambio, Vol. 27 No. 8, Dec. 1998.

12. Stone, L., A. Huppert, B. Rajagopalan, H. Bhasin and Y. Loya (1999). Mass Coral Bleaching: a Recent Outcome of Increased El Niño Activity? Ecology Letters, Vol. 2: 325-330.

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14. Wilkinson, C. (ed.) (1998). Status of Coral Reefs of the World: 1998. Australian Institute of Marine Science, on behalf of the Global Coral Reef Monitoring Network.

15. Wilkinson, C., O. Linden, H. Cesar, G. Hodgson, J. Rubens and A. E. Strong. Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change? Ambio, Vol. 28, No.2, March 1999.

Annex IV

SUMMARY OF MAIN POINTS AND ISSUES

The following tables were assembled from notes taken during expert presentations and discussions. They form the basis of the general conclusions and recommendations brought forth from the workshop, which are contained at the beginning of this document.

CONCLUSIONS

Biology
Coral reefs are the most diverse ecosystems in the oceans. However, we do not know how many species of even the main groups of organisms (corals, octocorals, hydrocorals, sponges, algae, etc.) coexist and interact in the system.
Coral reefs are among the most sensitive ecosystems to long-term climate change.
Corals are especially sensitive to elevated sea-surface temperature.
When physiologically stressed, corals may lose much of the their symbiotic algae, which supply nutrients and colour. In this state, corals appear white and are referred to as "bleached."
Corals can often recover from short-term bleaching; however, prolonged bleaching can cause irreversible damage and subsequent mortality.
In 1998, coral reefs around the world suffered the most extensive and severe bleaching and subsequent mortality on modern record; this widespread bleaching cannot be fully explained by localized stressors alone.
In 1998, tropical sea-surface temperatures associated with the El Niño Southern Oscillation (ENSO) phenomenon were the highest in modern record, topping off a fifty-year trend for some tropical oceans.
The majority of sites subjected to coral bleaching co-occurred with areas of high sea-surface temperatures and cannot be accounted for by localized stressors or natural variability.
The repercussions of the 1998 mass bleaching and mortality events will be far-reaching in time and space.
The threat posed by global warming to corals compounds the impacts of more localized anthropogenic factors that already place reefs at risk.
The coral-bleaching events of 1998 were highly variable with regard to taxonomic groups, geographic locations,

temporal scales, depths, and recovery rates.
Coral reefs are complex biotic systems bound by the relationships among various species and are particularly sensitive to changes impacting the symbiosis between corals and zooxanthellae.
Although coral bleaching can be induced by a wide variety of natural and anthropogenic factors, mass bleaching events are a temperature-driven phenomenon.
Coral bleaching is an indicator of thermal stress to coral reef ecosystems.
Communities that replace coral reef communities generally are not as biologically diverse or productive.
The impact of global warming on coral reefs can be as severe, or more severe, than impacts from direct localized stressors.
For isolated reef systems, recolonization of corals via long-distance dispersal of larvae from other sources may be limited, especially when the sink reefs are not down-current of the larval source reefs.
Coral reefs provide critical habitats for threatened species such as sea turtles and dugongs.
<u>Socio-economics</u>
Coral reefs provide many services, including fisheries, coastal protection, tourism, and medicines.
When major coral mortality occurs, human populations that depend on reef services face losses of local marine biological diversity, fisheries, and coastal protection.
Coral reefs are not only important for local fisheries, but they also play critical roles in the life cycle of some economically important migratory marine species, including tuna and mackerel.
Even those reefs with well-enforced legal protections as marine sanctuaries, or as areas managed for sustainable use, are threatened by global climate change. However, it is anticipated that such reefs, protected from anthropogenic stresses, would be more resilient to the added stress of climate change.
The incidence and severity of ciguatera poisoning are likely to be enhanced by bleaching through increases in algal cover after reef damage; ciguatera poisoning can have long-term debilitating effects on human health.
Mortality from coral bleaching might reduce the coastal protection function of reefs, leading to increased coastal erosion.
Reef-related tourism may be negatively impacted by actual or perceived reef degradation.

Local losses of biological diversity from coral bleaching may reduce discoveries of bioactive compounds of potential pharmaceutical value.
Analysis/prediction
Thus far, attempts to accurately assess the specific ecological and socio-economic impacts of bleaching have been hampered by a lack of data and information -- effective mitigation strategies are contingent upon such information.
Current models of global climate change project that ENSO events are increasing both in frequency and intensity with the likelihood of far greater impacts to coral reefs in the future.
Trends of the past century suggest that coral bleaching events may become more frequent and severe as the climate continues to warm, exposing coral reefs to increasingly hostile conditions.
A potential consequence of the steadily rising baseline of sea surface temperatures is an increase in frequency of mass bleaching events.

IMPORTANT QUESTIONS/FACTS UNKNOWN

What are the relationships (taxonomic, spatial, and temporal) between the vulnerability of corals and zooxanthellae to bleaching and mortality/recovery as a result of increasing sea surface temperature?
What are the mechanistic responses of corals and zooxanthellae to increasing water temperatures? How do these differ taxonomically and what are the maximum temperature thresholds for each taxon within various geographic localities and depths?
Are corals and their zooxanthellae able to adapt to rising sea temperatures and thus become more resistant to coral bleaching and mortality? If so, what are the time frames and mechanisms for such adaptation?
What is the effect of massive coral mortality on the abundance of fish (both food and non-food) species?
Are other invertebrates directly or indirectly affected by high-temperature events and coral mortality?
There is a need for better information to confirm the indication that coral bleaching and associated mortality is increasing significantly in frequency and severity on a global scale.
Can satellite imagery and aerial surveys/imagery be used as a cost-effective method to document bleaching events in developing countries?
What level of certainty can be ascribed to satellite "hotspot" bleaching predictions?

How do mortality, herbivory, organic enrichment, and other factors control the likelihood, duration, and effects of community-level phase shifts from coral reef ecosystems to algae-dominated ecosystems?
Do bleaching events make reef organisms (hosts and symbionts) more sensitive to other anthropogenic and natural events, such as pollution, cyclones and diseases?
What roles to microbes play in bleaching events?
What are the population structures, adaptabilities, ecology, and physiology of different zooxanthellae taxa?
What is the number of coral-reef species affected by increased sea-surface temperatures, and what proportion of the total number of species on a coral reef does this represent?
What are the life-cycle interdependencies of species moving between coral reefs and other ecosystems?
Does an increase in sea-surface temperature cause long-term shifts in coral-reef community structure? If so, how does the shift impact energy and nutrient cycling?
What impact do the "starting conditions" of reefs have on the response of corals to increasing sea-surface temperatures?
What is the relationship between coral bleaching events and toxic algal blooms?
Will increased acidification of sea-surface waters from climate change negatively affect the calcification process of corals, and hence their ability to grow (especially under increasingly frequent bleaching events)?
What will be the response of local fisheries and commercial fisheries to coral bleaching and mortality? What will be the time lag before the response?
What effect will coral bleaching and mortality have on tourism, the livelihoods of coral-reef-dependent communities, and coastal erosion? What will be the time lag before the response?

RECOMMENDATIONS

<u>Information-gathering</u>
Expand and coordinate international and national rapid response teams and long-term monitoring to measure coral bleaching and mortality.
Support the Global Coral Reef Monitoring Network (GCRMN) and associated regional networks, as well as data repository and dissemination systems such as ReefBase, expanding the network as resources permit.

Establish baseline data (biological, climatic, and socio-economic) for coral-reef ecosystems.
Conduct multidisciplinary research programmes that investigate the relationship among large-scale coral bleaching/mortality events, the health statuses of coral reef ecosystems, and global climate change.
Coordinate and strengthen targeted research programmes that investigate the long-term effects of coral bleaching and mortality on ecological, social, and economic systems.
Coordinate and strengthen research programmes that investigate the physiological tolerance and adaptive capacity of corals and zooxanthellae to acute and chronic stressors, especially high temperature.
Develop dynamic, predictive models of the impacts of global warming on the ecology of coral reef ecosystems, as well as the socio-economic factors influencing the human communities that depend upon these ecosystems.
Extend the application of early warning systems of coral bleaching by: (1) enhancing current NOAA AVHRR hotspot mapping via increased efforts at resolution in targeted areas, (2) involving managers and others in collaborative efforts to develop and refine early warning thresholds by making experimental products available during their calibration and validation phases, and (3) extending use to areas with no direct access to remotely-sensed data, via best means available, and develop mechanisms to automatically provide and verify this information.
Encourage space agencies and private entities to maintain deployment of existing and relevant operational and research sensors on satellites or other platforms, (i.e., AVHRR, Landsat 7, SeaWiFS, Space Shuttle, Space Station, LIDAR etc.) and to initiate design and deployment of specialized technology for shallow oceans monitoring.
Monitor crustose coralline algae and other macroalgae on reefs as indicators of reef status and resilience.
Monitor and investigate extent, recovery rates, resilience, and adaptability of corals and zooxanthellae with respect to increasing temperature.
Investigate the role of coral reefs as critical habitats for other marine species.
Investigate whether previously stressed reefs are more or less likely to be susceptible to the impact of coral bleaching.
Investigate the proximal and ultimate socio-economic impacts of bleaching.
Investigate the degree of human dependence on coral reefs; what are the implications of coral bleaching mortality to human food security, quality of life issues, forced migrations, etc.?

Determine ecological and socio-economic indicators of stress for use as "early warning signals".
Develop risk-assessment protocols that analyse potential coastal erosion and its economic consequences.
Capacity-building
Coordinate and strengthen these research programmes internationally through bilateral and multilateral programmes and instruments.
Emphasize and appreciate that coral reefs can be monitored as useful bioindicators of environmental stress, including global warming.
Develop an integrated strategy to address the effects on global warming on coral-reef ecosystems through the United Nations system, as well as through other international programmes and treaties.
Train and support taxonomists, of which there are few.
Establish training programmes to increase our capacity to assess short- and long-term changes in fish composition that are a consequence of coral bleaching and that impact on reef resilience potential.
Policy development/implementation
Apply the lessons learned from the 1998 mass coral-bleaching event to the next stages of climate policy while continuing to implement current commitments to reduce greenhouse gas emissions.
Consider coral bleaching an early warning of additional severe impacts to coral reef systems that could occur if temperatures continue to rise for prolonged periods.
Incorporate the lessons learned from the 1998 coral-bleaching events into the IPCC third assessment report.
Highlight that the collapse of coral-reef ecosystems could impact upon ecological processes of the larger marine system of which they are a part. Not only will local and commercial fisheries be impacted, but coastal ecosystems will be as well.
Marine diversity "hotspots" should no longer be considered refugia (safety zones) for marine organisms.
Protect reefs from local human impacts.
Promote alternative/supplemental livelihoods of coral-reef fishers where feasible (aquaculture, non-reef fishing, non-resource based activities).

Consider short-term assistance to tourist operators and fishers impacted by coral-bleaching events.
Diversify tourism beyond diving and snorkelling (sea kayaking, water sports, land-based activities) and reduce sole dependence on coral-reef species.
Increase advertising and market promotion once a coral-reef area has recovered.
Develop preventive strategies and regulations to protect public infrastructure and private property from increasing coastal flooding and erosion threats.
Provide public-health alerts concerning possible increases in ciguatera poisoning as a result of coral bleaching.
Encourage and support the development of integrated marine and coastal area management (IMCAM) programmes in those regions that do not already have them and integrated coral-bleaching response strategies.
<u>Financing</u>
Initiate long-term comprehensive funding initiatives.
Fund government-level and community-based programmes for coral reef monitoring that encourage local awareness and participation.
Promote and finance the transfer of know-how and technology among groups dedicated to coral reef conservation.
